# Artificial Neural Network for Real-Time Estimation of Basic Parameter of Signals

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***Abstract-*** **This paper presents for students instructions to using parallel algorithms, which can be implemented by analogue adaptive circuits employing some neural networks principles for estimation of parameters of signals in power system. Algorithms based on the standard least-squares (LS) criteria is proposed. The problem of estimation is formulated as an optimization problem and solved by using the gradient descent optimization algorithm. The corresponding architectures of analogue neuron-like adaptive processors are also shown.**

## I. INTRODUCTION

For the control and protection of electrical power systems it is desired to estimate in real-time the parameters of the basic waveform (fundamental harmonic) of voltages and currents.

For this purpose various numerical algorithms have been proposed, e.g. based on the Fourier and Kalman filtering [1-4]. Most of the algorithms are not fully parallel algorithms, so that the speed of processing is quite limited.

Recently, much attention has been paid to the methods of artificial neural networks because of their potential new algorithms and architectures for parallel computing systems [3-5].

In the paper are algorithms and along with them new architectures of analogue neuron-like adaptive processors for online estimation of parameters of sinusoidal signals, which are distorted by exponential DC components and corrupted by noise presented.

The problem of estimation of signal parameters is formulated as an optimization problem and solved by using the gradient descent continuous-time method. Basing on this approach were systems of nonlinear differential equations developed, that can be implemented by analog adaptive neural networks. The developed networks contain elements which are similar to the adaptive threshold elements of the perceptron presented by Widrow in [3].

## II. STATEMENT OF THE PROBLEM

When estimating the basic waveform of short-circuit currents the exponential DC component distorts the results. In this case the sinusoidal signal model has to be extended with an exponential term:

$$x(t) = X_a \sin(\omega t) + X_b \sin(\omega t) + X_c \exp(-\mathrm{X_d} t) \qquad (1)$$

in which

$X_a$ , $X_b$ are the amplitudes of the sinusoidal component,

$\omega = 2\pi \mathrm{f}$ where f is the frequency,

$X_c$, $X_d$ are the parameters of the DC component.

Let y(t) denote the noise corrupted measurement of *x(t)*, i.e.

$$y(t) = x(t) + e(t) \qquad (2)$$

where *e(t)* is the unknown error including random noise and distortion caused, for example, by measurement instruments or higher harmonics.

Consider the practical case where the signal of interest *y(t)* is measured during a finite duration of time and only N samples of the signal $y(t)|_{t=mT} = y(mT) = y_m$ , are available. Hence, the error $e_m$ can be expressed as

$$e_m = y_m - x_m \qquad (3)$$

where $x_m = x(mT)$, and T is the sampling interval.

There exists a need for an online algorithm that can directly provide estimates of the parameters on the basis of the given data samples $y_m$. To solve the problem using artificial neural networks, the key step is to construct an appropriate energy function E(**X**), so the lowest energy state corresponds to the desired solution. The problem can be formulated as to find a vector **X** which minimizes the scalar energy function

$$E(\boldsymbol{X}) = \sum_{m=1}^{N} \sigma_m \left[e_m(\boldsymbol{X})\right] \qquad (4)$$

where $\sigma_m[e_m(\boldsymbol{X})]$ represents a suitably chosen loss function.

In practice, the following cases have special importance [3-5]:

1) for $\sigma_m[e_m] = |e_m|$ the estimation problem is referred as the least absolute value signal model fitting;

2) for $\sigma_m[e_m] = e_m^2$ is the standard least-squares optimization problem obtained;

3) for $\sigma_m[e_m] = k_m e_m^2$ , with $k_m > 0$, the estimation problem is referred as the well-known weighted least-squares optimization problem.

The proper choice of the optimization criterion used depends on the distribution of the noise error in the sampled data. The standard least-squares criterion is optimal for a normal (Gaussian) distribution of the noise. Often, the signals of voltages and currents encountered in power systems are notoriously contaminated by impulsive noise and large isolated errors (outliers) caused by malfunctioning of some sensors or transient components. To reduce the influence of the outliers the iteratively reweighted least-squares criterion can be used.

## III. Estimation The Amplitudes of The Basic Components

Fast estimation of parameters of the basic components of voltages and currents from measured data is very important for measurement, control and protection tasks in electrical power systems. It is difficult to filter out frequency components close to the fundamental frequency, without delaying the filter response.

In this section an adaptive neural network for estimation the amplitudes $X_a$ and $X_b$ of distorted sinusoidal signals has been proposed.

The neural network was developed according to the signal model

$$x(t) = X_a \sin(\omega t) + X_b \cos(\omega t) + \mathrm{e} \tag{5}$$

As a loss function in (4) the standard least-squares optimization criterion has been chosen. The function E(X) can be minimized by implementing the steepest descent optimization algorithm

$$\frac{d\boldsymbol{X}}{dt} = -\frac{1}{\tau}\nabla E(\boldsymbol{X}) \tag{6}$$

where $\tau$ is the integration time constant and

$$\nabla E(\boldsymbol{X}) = \left[\frac{\partial E(\boldsymbol{X})}{\partial X_a};\frac{\partial E(\boldsymbol{X})}{\partial X_b}\right].$$

The gradient system can be rewritten in a scalar form as a system differential equations:

$$\frac{dX_a}{dt} = -\frac{1}{\tau}\sum_{\mathrm{m}=1}^{\mathrm{N}} \mathrm{e_m}\sin(\mathrm{m}\omega\mathrm{t}) \tag{7}$$

$$\frac{dX_b}{dt} = -\frac{1}{\tau}\sum_{\mathrm{m}=1}^{\mathrm{N}} \mathrm{e_m}\cos(\mathrm{m}\omega\mathrm{t}) \tag{8}$$

The above system of differential equations can be implemented by an adaptive analogue neural network, as shown in Fig. 1. The network consists of basic computing units: integrators, summers and multipliers. The network estimates the amplitudes of the basic components of signals.

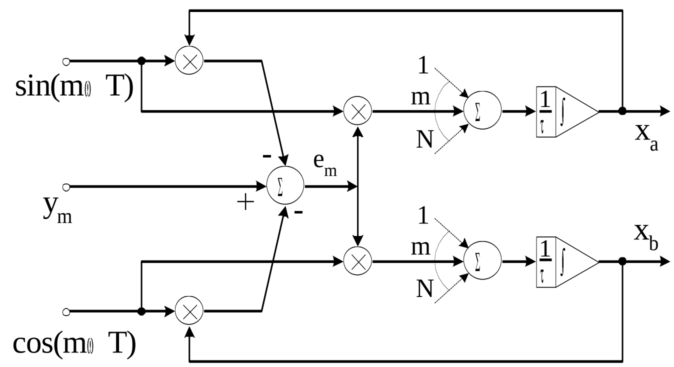


Figure 1. Artificial neural network with two neurons for estimation the amplitudes of the basic component.

## IV. Application of Neural Network

The laboratory tests utilize simulation of neural networks principles using Matlab Simulink environment [6]. Students taking a part in exercise are aimed at constructing a proper model of neural network according to accepted optimization criterion (Section II). Simultaneously, they have an occasion to improve their knowledge about parallel signal processing. The structure of modeled network applies typical elements: adders, multiplexers, integrators and generator of trigonometric functions. The main kernel of the scheme is based on two integrators associated with N signal channels. Optimization process serves calculation of basic component parameters: amplitude and phase.

Described exercise brings many didactic benefits to students. Starting from wide knowledge about different architectures of neural networks, through selection of optimization algorithm associated with noise level in investigated signal, to adaptation of sampling circuits and selection of suitable neural network structure.

## References


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